# CoBOP Coral Reefs: Optical Closure of a Coral Reef Submarine Light Field

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## LONG-TERM GOALS

The foundation of our long-term goal concerns the application of biological optics to the interpretation of what causes change in the color of the ocean, with specific reference to the interaction between oceanographic processes and the time and space distributions of suspended and submerged biota. The backbone of this goal is knowledge of optical closure, i.e. understanding the important factors which attenuate and reflect light from the water column and benthos.

## OBJECTIVES

The focus of our effort this year was to complete the compilation of observational and experimental data from our field work at Lee Stocking Island in 1998-2000, report the scope of our entire processed data set including early work under the CoBOP program in the Dry Tortugas (1995 and 1996) to other CoBOP investigators for distribution and production of manuscripts for publication.

## APPROACH

Our measurements have been directed toward the temporal variability of inherent optical properties and physical parameters of the shelf waters off Lee Stocking Island out to Exuma Sound as well as shallow water hemispherical benthic reflectance measurements in the 340-1000nm range for different species of corals, macroalgae, and microalagae.

To assess optical variability, time series profiles and a bottom mounted Aandera DCM12 upward sensing acoustic doppler current meter equipped with near bottom optical instrumentation was used to assess tidal, barotrophic and baroclinic flow. The unit samples five vertical depth bins for current speed and direction with tidal height measured by a quartz strain gauge. The optical package associated with the ADCP was a Seacat 19 CTD, WET Star *in situ* chlorophyll fluorometer and C-Star 488nm transmissometer. Profiles of water column hydrographic and optical properties were measured three times each day using a WET Labs AC-9 and CTD package equipped with Niskin water samplers to collect discrete measurements of particulate and dissolved spectral absorption and chlorophyll

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concentration. Profile and discrete sample data were also collected along offshore transects extending 25km into Exuma Sound in 1999 and 2000, hyperspectral remote sensing reflectance data were collected in 2000.

Hemispherical spectral reflectance was measured in the shipboard laboratory using an Analytical Spectral Devices FieldSpec reflectometer which scans 512 channels between 340-1000 nm. Divers collected specimens of macroalgae and coral, glass fiber filter pad concentrates were collected from the water samples and used to measure microalgae. Wetted specimens were illuminated at a 45-degree angle by a fiber optic projection source positioned at 0.5 meters from the specimen. Reflectance is recorded as a ratio of the specimen reflectance and the source light reflected from a Spectralon 99% standard. These measurements attempted to estimate species variability of the relationship between reflectance at visible and near infrared wavelengths (VNIR). We anticipated a relationship between VNIR and fluorescence; hence, variable fluorescence and the quantum efficiency of fluorescence were also measured simultaneously on each species. We hoped to establish a relationship between depth, VNIR and fluorescence yield in the *Montastraea faveolata*, a dominant coral on North Perry Reef.

## WORK COMPLETED

This year has required considerable computation to produce regressions, ratios, differences and derivatives between data sets for measurements made at different times and/or locations. The purpose was to compare neighboring water masses and benthic habitats, to create comparative time series data sets and to perform model runs for interpretation of our optical closure results. We have submitted two research papers for review. In the Journal of Marine Biology and Ecology, we have reaffirmed the close relationship between water clarity and coral growth. We have also reported our measurements of the optical properties of the water column and benthic reflectance to a special issue of Limnology and Oceanography.

## RESULTS

Clear ocean water from Exuma Sound extended onto the narrow seaward shelf east of Lee Stocking Island at depths less than 35m. CTD profiles at two sites (N. Perry Reef and the location of the ADCP mooring between North and South Perry Reefs) showed changes in water column physics throughout tidal cycles in each year with ca. $1^{o}$C stratification occurring in the upper 5-8m at high tide and a deeper mixed layer to within 2 meters of the bottom at low tide. Total variability in IOPs over the three field experiments was 30-35% and less dependent on the semi-diurnal tides than winds. The location of the ADCP mooring was specifically chosen to avoid the effects of ‘lagoonal’ water flowing out of Adderly Cut. The prevailing winds in May 1999 and 2000 were from the northeast, with occasional shifts to winds out of the north, south and west that would deliver clear, cold, less saline deep Exuma Sound water onto the shelf along the bottom. Attenuation increased as this water mixed with shelf waters until Exuma Sound water again penetrated the region.

We did not anticipate the degree of variability in the visible to NIR reflectance ratios that were observed. Part of this was due to our assumption that visible reflectance would be more variable than near infrared reflectance. Actually, it is the reverse, which has been known by terrestrial scientists for some time. The fact that marine organisms can reflect 50% greater near infrared light than visible light illustrates how little of the visible light is reflected. It is recognized that the internal structure of all plants is responsible for reflectance in the near infrared and is presumably traceable to the thickness of the thallus. There exists a large diversity in the structure of plants, which is undoubtedly responsible for changes in ratios observed in marine plants. A canon for terrestrial remote sensing community is that healthy vegetation is characterized by high reflectance in the near infrared relative to low in the visible region. Our observations support this theory. We have used the reflectance ratio 687nm/800nm, which is not constant for marine plants and corals. The reflectance value at 687nm ranges from 1% to 40% while the reflectance at 800nm ranges from 1% to 100%. The extreme range of values at 800nm we believe to be due to the organism's internal structure. The data from Lee Stocking Island obeyed the theory of terrestrial biologists in which high values of reflectance at 800nm and low values at 687nm correspond to the healthier organisms.

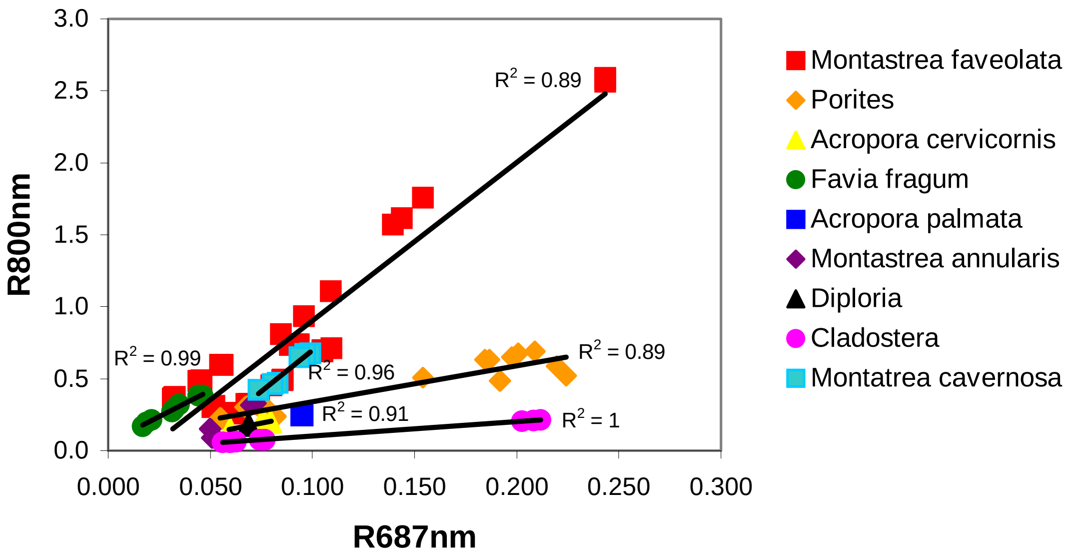


***Figure 1. Lee Stocking Island and Mote Marine Lab***
***[Reflectance at 800nm versus 687nm; each genus has a strongly correlated relationship]***

Within the matrix of reflectance values measured, we observed a strong relationship from genus to genus. Each genus seems to have a unique linear relationship amongst itself. For example, *Cladostera sp.* has a slope of 1 with an $r^2$ =1(only two samples were measured), *Porites sp.* has a slope of 2 with an $r^2$=0.99, *Favia sp.* has a slope of 7 with an $r^2$=0.99 and *Montastrea sp.* has a slope of 8 with an $r^2$=0.23. To test this theory we combined the *Montastrea sp.* data from Lee Stocking Island with that taken at Mote Marine Lab on the same genus (Figure 1). The slope increased slightly to 11 but the $r^2$=0.89. The same relationship was also observed to be site specific, which we attribute to the dominant genus at that location (Figure 2).

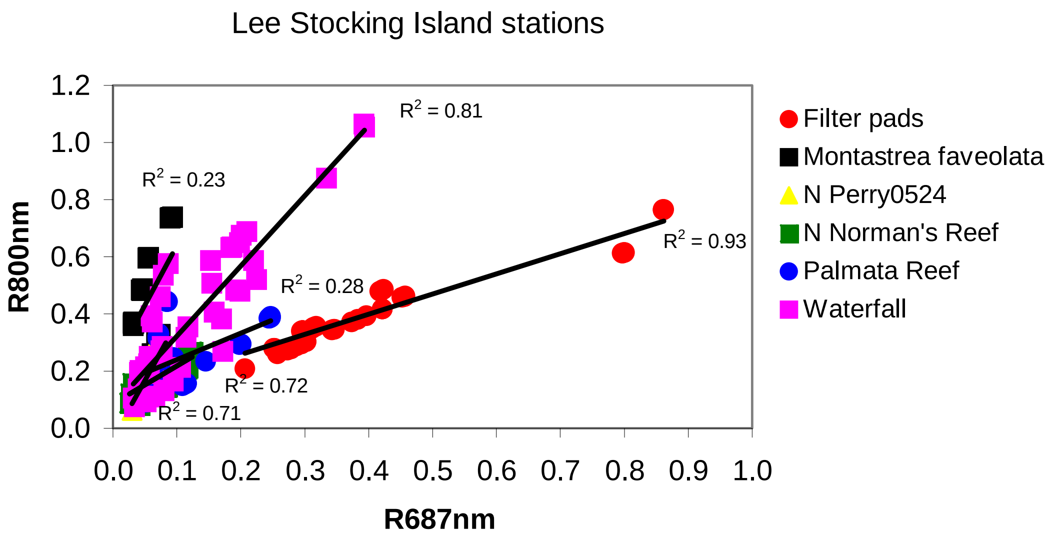


***Figure 2. Lee Stocking Island***
***[Reflectance at 800nm versus 687nm; each site location has a strongly correlated relationship]***

The reflectance ratio of 687nm/800nm can be roughly related to the photosynthetic efficiency of photosystem II, however there is not a real close trend in the data. In the extreme cases a high reflectance ratio is correlated to a low efficiency factor. High reflectance at 800nm compared to that at 687nm corresponded to a high efficiency factor.

## IMPACT/APPLICATIONS

The addition of the measurement of reflection at wavelengths in the near infrared provides an optical diagnostic never before available for benthic studies. The advantage provides the observer with improved capabilities for the identification and estimation of the biomass of marine macroalgae as well as indices of potential growth.

In the passive mode this approach, because of water absorption, is confined to shallow water habitats- yet can be applied to the identification of surface blooms of algae and other plant material in the surface layer of water masses. In the active mode, for example using laser light as a NIR source, bottom vegetation can be scanned, i.e. mapped. This will be a useful addition for the detection and characterization of shallow underwater features such as natural and artificial reefs

## RELATED PROJECTS

Our research is supported by the projects of Mike Lesser, Charles Mazel, and Paul Falkowski. All these, including our research, ask basic questions concerning time/space distribution of benthic habitat, reasons for the biodiversity, and the role of microclimate on growth processes. Our collegial relationships include Pam Reed/Eric Louchard and Dick Zimmerman/Sally Wittlinger

## PUBLICATIONS

Yentsch, C.S., S. W. Yentsch, C.M. Yentsch and D.A. Phinney. The relationship between visible and near-infrared reflected light from corals, macroalgae and micralgae. Submitted to CoBOP Special Issue of Limnology and Oceangraphy.

Yentsch, C.S., C.M. Yentsch, J.J Cullen, B. Lapointe, D.A. Phinney and S.W. Yentsch. Sunlight and water transparency: Cornerstones in coral research. Submitted to Journal of Experimental Marine Biology and Ecology.